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TITLE: A MICROPROCESSOR-BASED CONTROLLER FOR A LIQUID HYDROGEN TARGET REFRIGERATOR

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A MICROPROCESSOR-BASED CONTROLLER FOR A
LIQUID HYDROGEN TARGET REFRIGERATOR

by

Allan J. Gjovig, James D. Little, and Jan K. Novak*

ABSTRACT

A microprocessor-based cryogenic refrigerator controller developed at
the Los Alamos Scientific Laboratory provides automatic cooldown and subse-
quent monitoring of liquid hydrogen targets. The controller performs the
initial cooldown of the cryogenic system and provides continuous monitoring
of the important system parameters. An alarm is sounded to summon an opera-
tor in the event of any parameter exceeding predetermined limits.

INTRODUCTION

Medium-energy physics experiments at the Clinton P.
Anderson Meson Physics Facility (LAMPF) of the Los
Alamos Scientific Laboratory have many requirements for
cryogenic liquid targets, particularly liquid hydrogen,
a very dense form of protons in a simple, easily under-
stood molecule. Each LAMPF cryogenic target system
uses a commercial refrigerator (capacity 10 W at 20° K
target temperature) and a custom-built gas handling
unit with which one purges contaminant gases, controls
flow of the target gas, and provides safety devices
(see Fig. 1). A proportional controller senses target
pressure and maintains it within ±0.1 psi by regulating
current in a target heater. The refrigerator, gas hand-
ling unit, pressure controller, and target instrumenta-
tion are read and operated from a portable control con-
sole located about 150 ft from the target.

Operation of the original control console was
completely manual. From system startup to steady-state
operation required the near constant attendance of a
skilled cryogenic operator for a period of from 6 to
24 hours. There were always more targets than techni-
cians, thus creating problems of scheduling or of addi-
tional costs in hiring extra technicians. Once steady-
state operation was reached, safety considerations re-
quired continual attendance by a monitor operator,
usually an experimenter. The monitors were often in-
experienced students or overworked physicsts whose
attentions lay elsewhere.

To solve these problems, a microprocessor-based
liquid hydrogen refrigerator controller has been devel-
oped (see Fig. 2). The controller frees the technicians
and experimenters to do work that only humans can do,
allows the systems to be started at the convenience of
the experimenters, and provides for safer operation
through constant monitoring.

Since the six original control consoles were de-
signed and fabricated several years ago without provi-
sion for computer control, the problems of manual com-
puter mode switching and of interfacing to the computer
equipment were immediately encountered. The old system
incorporated alternate action switches for all of the
valves, pumps, etc., mounted in a graphic display panel.
All of the control relays were mounted on a large panel
in the back of the rack. In addition, the 150-ft con-
trol cables represent a sizable investment.

The design criteria for the interfacing were as
follows:

1) Fail safe in that loss of power or computer causes
the refrigerator system to go to a safe mode.

2) Operator can switch from manual mode to computer
mode at any point in the sequence and the computer
will continue on without a discontinuity (assuming
operator follows same check list that the computer
follows).

3) Operator can take control away from computer at any
time and there will not be a discontinuity.

4) Use all of the old cable system and as much of the
existing controls and hardware as possible.

5) Provide a graphic display of the status of the
system.

6) Provide a hardcopy (printer) record of the system
activity and the alarm activity.

7) Use LASL standardized local control modules.

8) Provide ground isolation as well as power isolation
between the "dirty" power that drives pumps, com-
pressors, etc., and the controls power supplies.

9) The system once started should be able without
operator intervention to do a system turn-on from
the warm state.

10) The system should be able to constantly monitor its
own progress in the startup as well as check for
error/alarm conditions.

11) The controller system shall serve as an additional
level of safety. All hardwired safety interlocks
and mechanical safety devices will remain active.

At startup, the controller sets valves appropri-
ately and causes vacuum pumpdown to begin. Once the
required vacuum has been achieved, a series of system
purges is begun to eliminate foreign gases from the
plumbing. After the purge is completed. system cool-
down is initiated. When the cooldown is complete and
the system has reached equilibrium, the controller auto-
matically switches to a monitor mode in which system
parameters are continually measured and compared to a
normal range of values. The parameters are periodi-
cally printed, along with time and day. Trends toward
marginal performance of one or another of the refriger-
ator subsystems can often be detected and corrected be-
fore a failure occurs. Out-of-bounds parameter measure-
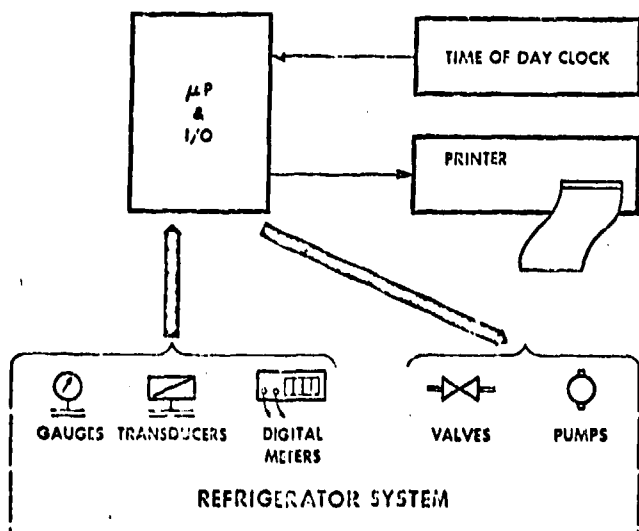ments are printed as soon as they are detected, and

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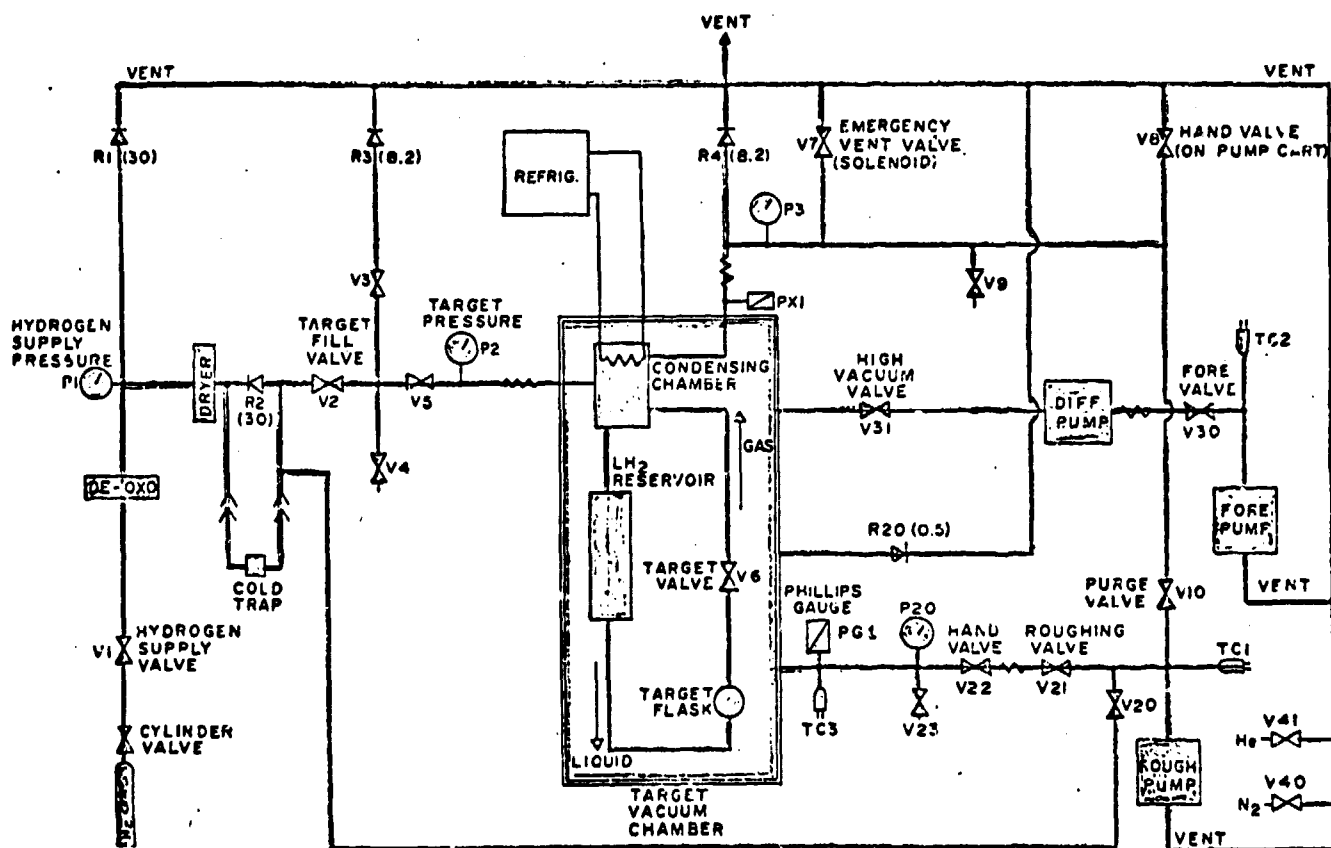
PIPING SCHEMATIC REFRIGERATED H₂ TARGET
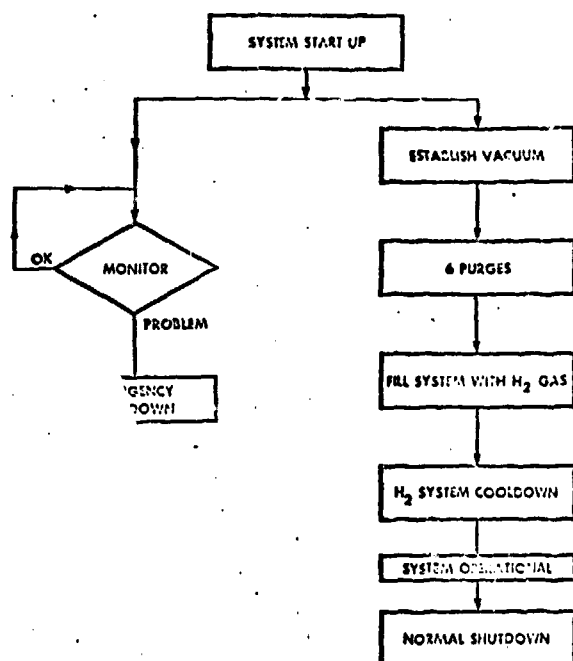

CONTROLLER BLOCK DIAGRAM

Fig. 2

visual and audio alarms are given, also. Operators can then intervene and, possibly, correct the problem. If the problem is not corrected, the controller will shut down the system safely before other system components are damaged (see Fig. 3).

Controller Hardware

The controller is an 8080-based system containing up to 12K bytes of PROM and 2K bytes of read/write memory (RAM). Thirty 8-bit I/O ports are provided in the form of ten 8255A programmable peripheral interfaces. Inputs are used to sense status of the refrigerator and to read the time-of-day clock. Outputs control the refrigerator pumps and valves and drive the digital printer. The digital printer can be driven directly from the output ports, but the refrigerator control lines must be isolated and, of course, must include power gain. The isolation and power gain are provided in standard NIM modules.

The output of the time-of-day clock is displayed on the controller front panel for the benefit of the operator. More importantly, however, the time in BCD is latched in registers which are connected to microprocessor input ports.

An Alarm/Status board contains the electronics to drive the front panel display LEDs and two separate alarm circuits. One alarm is triggered by a pulse from

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SYSTEM FLOW DIAGRAM

Fig. 3

unique status code is a powerful troubleshooting aid for the cryogenic technician The printer hardcopy provides a permanen*. record of system behavior.

Two digital panel meters are used for analog-to-digital converters in the system. The meter inputs are connected to pressure-to-voltage transducers and the BCD outputs of the meters are connected to microprocessor input ports.

Software

In a system program such as this, a number of circumstances arise in which it is desirable to do two tasks in parallel. One example is the requirement of establishing vacuum in two independent vacuum systems at the same time. This requires two independent, parallel paths that are time-shared in the software. Of the several time-sharing techniques available, we chose to utilize the time-driven queue shown in Fig. 4.

SLOT 1	$ADDR_1$ (HIGH)	$ADDR_1$ (LOW)	t_1 (DAY)	t_1 (HOUR)	t_1 (MINUTE)
SLOT 2	$ADDR_2$ (HIGH)	$ADDR_2$ (LOW)	t_2 (DAY)	t_2 (HOUR)	t_2 (MINUTE)
SLOT 3	$ADDR_3$ (HIGH)	$ADDR_3$ (LOW)	t_3 (DAY)	t_3 (HOUR)	t_3 (MINUTE)
SLOT 4	$ADDR_4$ (HIGH)	$ADDR_4$ (LOW)	t_4 (DAY)	t_4 (HOUR)	t_4 (MINUTE)

Fig. 4. Memory Diagram of Queue

The queue consists of four slots. Each slot requires five bytes of memory, two to hold the address of the task and three to hold the time (day, hour, and minute) at which the task is to run. When two functional parallel paths are to be executed at the same time, the first task in each path is placed in the queue along with its desired run time. Unused slots are zeroed. A SCAN routine searches for a valid task in the queue, and when one is found, the desired run time is compared to current time. If current time is greater than, or equal to, the desired run time, that slot in the queue is zeroed and a jump is made to that task address.

In this application, a typical task is to test a bit to determine if a given vacuum has been established. If the test passes, the next task in the path is put in the queue and the SCAN routine is called. All tasks have a maximum allowable time till completion. If a test fails, a further test is made to see if time out has occurred. If time out has not occurred, the task is simply placed in the queue again. If time out has occurred, the task is placed in the queue again and an alarm is sounded to alert the operator. With a task re-queued, the SCAN routine takes over and checks the queue for a task in the other functional path. In this way, up to four functional paths can be working at the same time, completely independent of each other. Four is not a limit, but was chosen as the maximum number required in this application.

Conclusion

Although the digital hardware and the software were designed for this specific application, the designs were kept flexible and general to allow the equipment to be easily reconfigured for other automated check list applications.

a microprocessor output bit and is used if the controller detects an out-of-limit condition. The other alarm is triggered by a pulse from a "watchdog timer" circuit if the microprocessor has not retriggered the timer in the last five seconds. The intent was to alarm the operator in the event of a CPU failure. Both alarms are SCR type so that the alarm condition is maintained until an operator physically pushes a button. The alarm cannot be cleared by the microprocessor.

A Program Status Board contains eight magnetic latching relays and the circuitry to drive the relays. The state of the magnetic latching relays is controlled by microprocessor output lines and can be read by input lines. As each functional step in the program is completed, the pattern of these eight bits is uniquely changed. In the event of a power failure, the bit pattern is not disturbed. When power is resumed, the bit pattern can be read by the microprocessor and program execution can proceed from approximately where it left off. The advantage is that starting over from the beginning may not be required. A sound vacuum may have been established, for example, and attempting to re-establish the vacuum would simply be a waste of time and resources. This, of course, applies only to power failures of reasonably short duration. Long-duration power failures will be accompanied by loss of vacuum and/or increases of temperature, so in such cases, a complete system startup will be required. However, long-duration power failures will allow time for a cryogenic technician to guide the system startup.

A six-column numeric digital printer is a key part of the system. As each functional step in the process is completed, the printer indicates this by printing the appropriate status code, the time of day, and the day number. Should a functional step fail for any reason (e.g., vacuum leak, broken pump, loose connection, etc.), a specific failure status code is printed. This